Sustainability & Satisfaction:
Findings from field studies of office buildings in the UK and India

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ABSTRACT: This paper presents results of field work exploring the relationship between energy use for ventilation and space conditioning in office buildings and the end-user satisfaction. The correlation between building energy use and occupant overall satisfaction is evaluated to assess the performance and acceptability of ventilation types. The role of significant environmental parameters in this relationship and variations in their relative importance with differing contexts are examined in detail. Further, less explored psychological factors associated with the various contexts are also investigated for their role in influencing the occupant satisfaction response and thus the relationship with the energy use.
Keywords: comfort, energy, ventilation, satisfaction, adaptation

INTRODUCTION

Large amounts of energy are consumed by ventilation systems in buildings to meet satisfactory thermal and indoor air quality requirements for occupants. This trend, especially true of office buildings, has had significant impacts on global consumption levels. Buildings today constitute one of the main consumers of the world's energy. Growing environmental concerns as well as energy security, however, raise certain questions in relation to the justification of these high levels of energy use by buildings. Are high levels of energy use in buildings necessary for delivering a better environment and satisfaction for the end-user? To what extent does the satisfaction of building occupants depend on parameters affected by energy use? Can there be alternatives that offer occupant acceptability in more sustainably designed buildings? These questions have not yet been adequately addressed in research. The study presented in this paper provides insights into answers to the above questions by evaluating the relationship between energy used by buildings for their ventilation and conditioning requirements and the occupant satisfaction therein and examining the modulating factors for the satisfaction response. These attempts are aimed to help define predictive models and establish regulatory standards that will eventually help improve the performance of sustainable building design, making them more acceptable to occupants, as well as designers, and building owners.

BACKGROUND

The background has shown that ventilation and conditioning constitute the prime consumers of energy in buildings. Responsible in large part is the preponderance of high energy mechanical systems for these services. These systems are often justified over non mechanical natural options for ensuring occupant comfort with environmental conditions in buildings. However, although with the technology available there is no technical limitation in providing systems that can result in requisite indoor conditions, these could be fairly energy intensive and it is not clear whether they are really required [1]. It is unclear if the increased energy use of highly mechanized control systems makes the occupants of buildings using them any happier than their counterparts in other buildings, or has any bearing on their satisfaction with the indoor environment. On the contrary, studies have indicated that occupants of mechanically conditioned buildings can often be critical of their environments and those of low energy naturally ventilated ones more tolerant. One study in the UK [2], made comparisons of occupant satisfaction with the ventilation type, and showed that the overall occupant response levels can vary quite a bit, and so no conclusive answers could be drawn.

In considering the above relationships the indoor environmental conditions delivered by the energy use may bear importance as the occupant satisfaction may bear more direct relationships to the perceptible environment than to the energy use itself. In this respect, assessments of an overall holistic perspective

of this response are considered of particular significance, being vital to the acceptability of ventilation systems, and the main driver of change. Some attempts in the past have looked at this combined overall satisfaction response assessing the environmental performance in totality, but these have been mostly limited [3][4][5]. An assessment of the environmental determinants of this aspect, however, may deserve attention when considering relationships with energy use for building ventilation and conditioning.

With regard to this the role of adaptive mechanisms that may influence the occupant response, has, moreover, also been recently brought to attention. Studies suggest that people interact with the environment and adapt to it at various levels to find satisfaction [6]. Perceptions of well-being can therefore be complex, and can include social issues as well as design and health ones [7]. This has been pointed out specifically with reference to differences in environmental satisfaction between ventilation types [8]. Such ideas of adaptation have received considerable interest although efforts at a systematic and comprehensive evaluation of the factors involved have been few. Factors such as control, associations, expectations, and habituation, have been highlighted as significant factors deserving investigation.

Varying perspectives have been thereby offered to explain the acceptability of low energy sustainable design in buildings but none have been fully explained. The competence of such alternatives therefore needs to be more conclusively established. In this regard it is significant to understand the relationship between the use of energy by buildings, and their performance in terms of the satisfaction of the end-user and the key determinants and influencing factors identified, as undertaken in the study presented in this paper.

METHODOLOGY

The investigations approach the questions posed in this study by using field study buildings with different ventilation approaches. These were selected falling on a continuum with broad categories ranging from air-conditioned, mixed mode, advanced naturally ventilated, to naturally ventilated types, representing different energy uses. This continuum was modelled on one for adaptive opportunity [9] but modified to represent different levels of mechanization and control levels for building systems. A total of twelve study buildings were selected in the UK and India [Figure 1, Table 1]. These locations presented contrasting contextual settings with differences in climate and pollution, as well as socio-economic and cultural backgrounds. The study further also addressed seasonal differences of hot and cold weather for each situation.

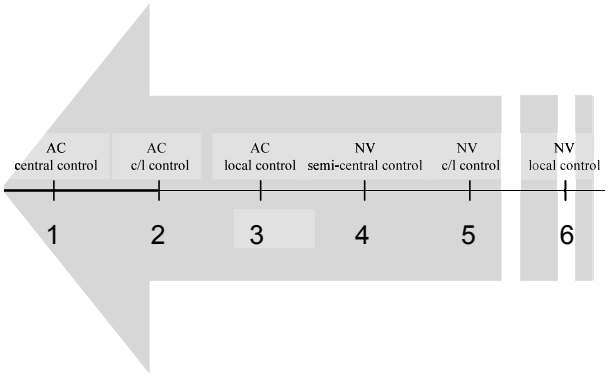


Figure 1: Schematic diagram of the study continuum

Table 1: List of field study buildings in the UK & India

	No.	Project	Code	Type
	1.0	BP Sunbry	**BPS**	AC
	2.0	William Gates Building	**WGB**	MM
	3.0	IBM Hursley	**IBM**	MM
	4.0	Centre for Mathematical Sciences	**CMS**	ANV
	5.0	Aldwyck Housing Association	**AHA**	ANV
UK	6.0	BP Institute	**BPI**	NV

	No.	Project	Code	Type
	1.0	Transport Corporation of India	**TCI**	AC
	2.0	American Institue of Indian Studies	**AIIS**	MM
	3.0	Central Institute for Educational Tech.	**CIET**	MM
	4.0	Torrent Research Centre	**TRC**	ANV
	5.0	Solar Energy Centre	**SEC**	NV
India	6.0	Development Alternatives	**DA**	NV

The primary method of investigation involved the use of surveys. These included information gathering, occupant questionnaires, and environmental monitoring, to collect data on energy use, occupant satisfaction, specific perceptions, adaptive aspects, and environmental criteria. A total of 395 responses were collected in the UK and 298 in India from a combination of electronically and manually administered questionnaires in surveys conducted seasonally. The data was then compiled and evaluated using computational statistical techniques to investigate relationships, trends, and dependencies. The general linear model (GLM) approach served as the primary statistical analysis tool, and correlation and regression techniques were used as complementary and confirmatory statistical methods.

RESULTS

The first set of investigations explored relationships between energy use and occupant satisfaction in the study buildings.

Graphs plotting energy use for each field study building against the mean occupant overall satisfaction scores were evaluated for discernable patterns. No clear trends emerged with the total energy use or the conditioning energy use. Some approximate groupings, however, did become apparent with location. Cases in the UK showed a varying range of outcomes, but in the Indian context, it seemed that comparatively stronger climatic conditions probably warranted the use of the additional energy for delivering higher satisfaction [Figure 2].

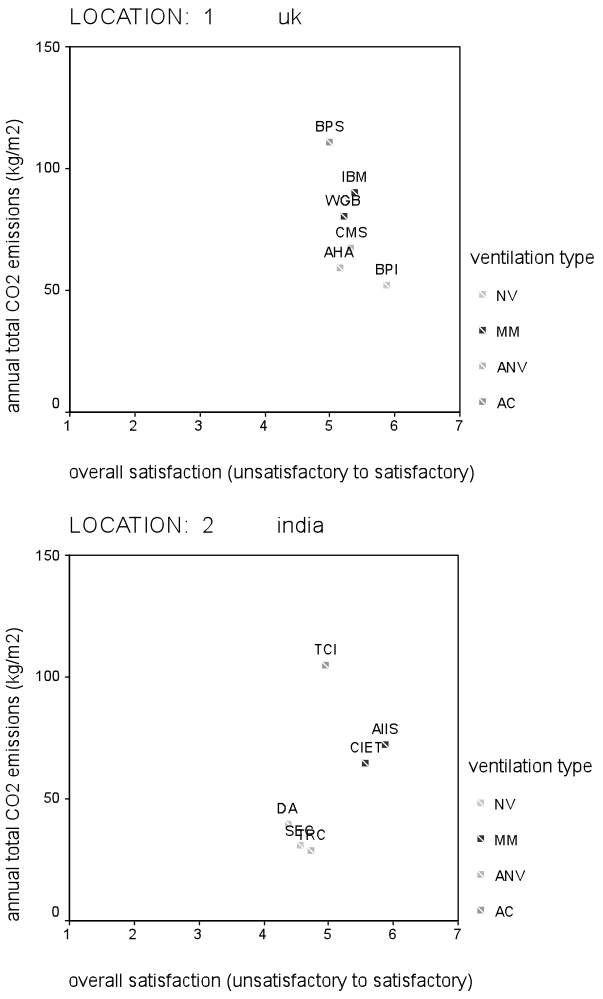


Figure 2: Overall satisfaction plotted against energy use

These observations were further examined using more reliable statistical methods and tested for significance.

Satisfaction responses were first compared between ventilation type representing different energy uses. This showed that occupant satisfaction could differ ($p<0.05$) between ventilation types of air-conditioned, mixed mode, advanced naturally ventilated, and naturally ventilated systems [Figure 4]. In general the mixed mode types were seen to have better outcomes.

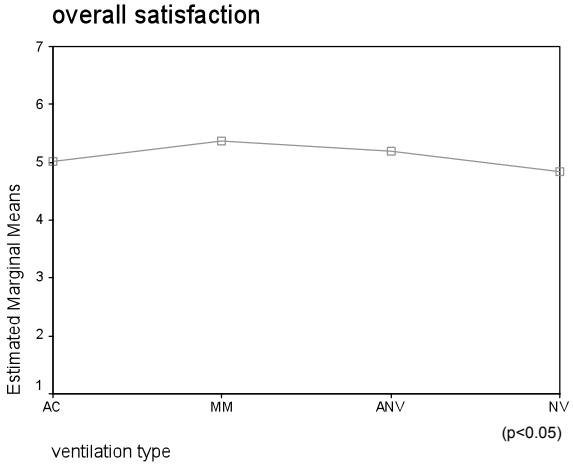


Figure 3: Overall satisfaction plotted per ventilation type

This variation with ventilation type was, however, found to be dependent on the context of location. Significant differences in satisfaction vis-à-vis ventilation type were seen for the Indian location, but not so much for the UK, indicating that the latter was probably contributing to the pooled results. This observation was along the lines of that made with the graphs before. Differences in satisfaction were further influenced by season and were especially significant for hot weather ($p<0.001$) in India where mixed mode buildings types were mostly found to be the best.

Satisfaction results were also compared directly with the energy use trends. Regressions showed relationships to be weak, explaining the unclear trends in the plotted graphs before ($Rsq=0.016$, $p<0.01$), but again indicated that medium energy users exemplified by mixed mode types usually performed best. As the consumption of these medium energy using types was often not much higher than the lowest consumers, the result was considered significant in supporting low energy design in meeting good satisfaction performance. Mixed mode buildings types have been indicated in other recent studies too to be better than benchmark with respect to occupant satisfaction

responses [10][11]. Context effects, however, indicated some role of factors related to it in this case too.

The second set of investigations investigated the environmental determinants in explaining these outcomes.

For this, the predictability of the satisfaction response was explored first from perceived variables representing environmental parameters. Statistical models found that overall satisfaction had significant contributions from occupant perceptions of thermal comfort and indoor air quality satisfaction, together accounting for over half of the variance in the response [Table 2]. The good predictive power confirms assumptions in this thesis and assertions in literature of the representativeness of these variables for the environment affected by ventilation and conditioning in totality. Of the two variables, satisfaction with indoor air quality was found to have the dominant impact, contributing to 50% ($p<0.001$) of the predictability of the overall response, with thermal comfort contributing about 5% ($p<0.001$), both as linear relationships.

Table 2: Contributions to overall satisfaction from satisfaction with the thermal and indoor air quality environment

Tests of Between-Subjects Effects

Dependent Variable: overall satisfaction (unsatisfactory to satisfactory)

Source	Type III Sum of Sqs.	df	Mean Square	F	Sig.
Corrected Model	750.467 a	12	62.539	67.252	0.000
Intercept	3945.145	1	3945.145	4242.452	0.000
Q1C	77.41	6	12.902	13.874	0.000
Q3F	324.976	6	54.163	58.244	0.000
Error	586.78	631	0.93		
Total	18319	644			
Corrected Total	1337.247	643			

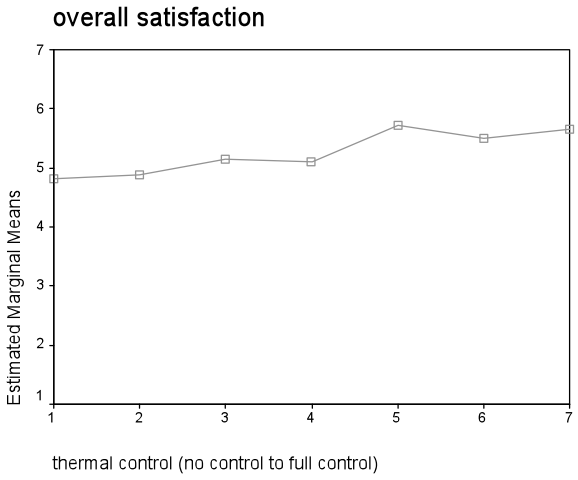
a. R Squared = .561 (Adjusted R Squared = .553)

The difference in weightage of the two variables, however, appears contrary to most findings in previous research. On the other hand, it may point to the possibility of changing orders of importance of variables. Baker and Standeven [12] mention that at times the awareness and importance of stimuli may increase when factors cause variation in other stimuli to be reduced to within the tolerance range or be completely eliminated. This may also responsible for contextual differences in importance. Season, in particular, was found to be significant ($p<0.01$) in causing such differences in this study. Possibly there were factors associated with this context, such as climatic or even cultural, that produced differences in sensitivity to the environmental variables.

The contributions of environmental criteria were also examined from the measured parameters themselves. These, however, showed weak links of satisfaction variables with the environmental data indicating limitations to the significance of the result arising from lack of comprehensive measurements.

The third set of investigations related to exploring the role of psychological adaptive factors in explaining contextual differences in satisfaction.

Explorations included the effects of perceived control, considered significant in the literature review. These found that responses for thermal and ventilation control were important and linearly related to the occupant satisfaction ($Rsq=0.12$, $p<0.001$) [Figure 5]. Control and comfort have been shown to be generally higher in lower-energy buildings in some other studies too [13]. The significance of perceived control reflects the inherent adaptive urge of humans of exercising choice as part of instincts for survival. This is because control can facilitate tailoring of the environment to individual requirements, including meeting the intrinsic need for variation when desired, potentially ensuring satisfaction for everyone all time. The fact that control adds value even when not exercised is notable and deserves attention in future research.



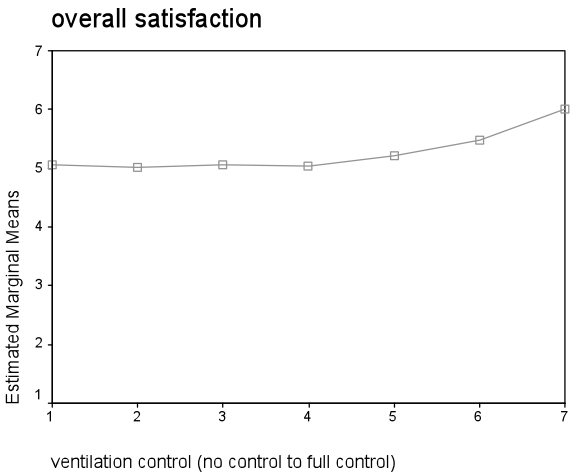


Figure 4: Overall satisfaction plotted against thermal & ventilation control

In addition to perceptions of control, beliefs also of some other environmental and non-environmental factors, not directly addressed by this study, were found to be important. Anecdotal evidence from open comments in occupant survey questionnaires brought forth occupant opinion on factors such as noise, light, etc. in addition to thermal comfort, air quality, and control that were already concerns in the study. In addition to direct effects on satisfaction, additional factors such as these may be particularly notable quite often for their indirect effects from associations with other perceptions based on previous primary or secondary inputs. For example certain type of lighting or noise levels may be associated with generally well-managed and healthy environments in turn improving satisfaction levels as well. Such factors therefore deserve further exploration in future research and possible incorporation into predictive models for satisfaction.

Explorations were further also made into occupant expectations of satisfaction. These attempted to examine whether expectations resulted in affects on the actual satisfaction experienced in particular environments. Investigations taken up for the UK context, addressing differences in ventilation types, found that expectations of satisfaction with thermal or indoor air quality conditions in specific types, did not necessarily influence the final satisfaction for these aspects in those types. This is contrary to references made in some research, with respect to thermal comfort, of relaxed expectations driven by high-perceived control and a greater diversity of experiences, as reasons for high satisfaction and higher tolerances in buildings that were naturally ventilated. It is concluded that expectations probably did affect occupant perceptions, but, as the chances of their being met could vary with each individual based on their personal history of past primary or secondary exposures, these may not have a consistent effect in any one direction on the satisfaction response. Larger climato-cultural or socio-economic factors, represented by different locations or even seasons, however, may be worth further research in this respect. Viewed more practically, on the other hand, expectations may really essentially reflect the means that an occupant has of realizing his desires, reflecting back to the importance of perceived control found in this study [14].

In addition some habituation effects in the expectations of conditions provided were also explored. Evaluations of the influence of occupant habituation to conditions provided by different ventilation systems, on the satisfaction expected from them, however, did not reveal any consistent effects in this study. This inference was derived from results that showed that occupants of particular ventilation types did not necessarily vote their own type as most likely for meeting requirements of satisfactory thermal or even air quality conditions. Habituation, however, does have some evidence in its support in past research, where occupant comfort levels have been shown to depend on the history of specific exposed conditions. These effects should therefore not be ignored. Habituation effects resulting from past experiences may relate to effect of expectations referred to before as well, where familiarity with the environment promotes satisfaction by increasing the chances of met expectations. With respect to differences with ventilation type, the use of control by occupants to tune conditions may be of interest for its affect on occupant tolerance levels, along with that on building energy use. Habituation should therefore remain a subject of ongoing research.

DISCUSSION

The findings of this research offer inputs that can present especially useful contributions for future practice.

Results establish that while energy use varies with the ventilation and space conditioning strategy it may not always relate to the satisfaction of the end users. This clearly demonstrates the ability of sustainable low energy approaches to deliver high levels of satisfaction. In this instance this is exemplified by mixed mode building types in most cases, although in others the lack of a particular trend indicates the chance of any type including even naturally ventilated low energy ones of having good performance. This provides requisite proof that can encourage buildings owners to be more confident of investing in design approaches and ventilation technologies that are more energy

efficient, knowing that these are capable of ensuring occupant comfort and well-being and can offer returns in terms of resulting productivity benefits.

The research, further, identifies environmental parameters significant for the satisfaction response and may explain these trends to some extent. Parameters such as indoor air quality perceptions are found to be important for holistic assessments of satisfaction although importance could also vary with context. This presents valuable information for the designers of buildings and their services by pointing out areas for specific attention, to balance the performance of critical environmental parameters. The lack of environmental parameters to be able to fully explain the satisfaction response, and variations in importance with context, however, highlights the possible role of adaptive factors in these relationships.

The role of psychological adaptive factors is finally found likely in accounting for these observations. Amongst the factors investigated, those of perceived control are found to be most notable. Association effects with factors such as light, noise, and job satisfaction are also indicated. The processes of expectations, speculated in some previous studies, on the other hand, are not found to be particularly influential, although the processes of habituation are considered worth further investigation. This knowledge can take the form of systems and controls that occupants can intuitively understand and associate with, and of awareness programs emphasizing the effectiveness and importance of sustainable design to prepare occupants to be more receptive.

CONCLUSIONS

The study on the whole, concludes that energy use in buildings and user satisfaction are not necessarily related. It suggests that high levels of satisfaction can be achieved with low energy design, and at a broad level, points out critical environmental criteria and pertinent psychological mechanisms that can be used to maximize satisfaction while limiting the energy use. It is considered that the above suggested options for field applications drawing on the outcomes of this research may be able to increase the adoption of more sustainable alternatives for improved occupant satisfaction and drive the trends for future practice and research.

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